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Abstract

The National Aeronautics and Space Administration (NASA) and the Air Force Research Laboratory (AFRL) have recently established a collaborative effort to support the development of polymer-based, lithium-based cell chemistries and battery technologies to address the next generation of aerospace applications and mission needs. The overall objective of this development program, which is referred to as PERS, Polymer Energy Rechargeable System, is to establish a world-class technology capability and U.S. leadership in polymer-based battery technology for aerospace applications. Programmatically, the PERS initiative will exploit both interagency collaborations to address common technology and engineering issues and the active participation of academia and private industry. The initial program phases will focus on R&D activities to address the critical technical issues and challenges at the cell level.

Background

Rechargeable lithium-based battery technologies offer significant performance advantages and cost benefits for a variety of future aerospace, as well as terrestrial

missions. Major projected advantages over more conventional battery technologies include reduced mass and volume of the energy storage system, enhanced system reliability and flexibility and lower power system life-cycle costs. NASA is considering the utilization of lithium-based batteries in many future aerospace applications such as planetary landers, planetary rovers, planetary orbiters, Earth-orbiting spacecraft for both geosynchronous (GEO) and low-Earth-orbit (LEO) missions, reusable launch vehicles (RLVs) and astronaut equipment. In addition, the feasibility of replacing the hydraulic Auxiliary Propulsion Unit (APU) of the existing Space Transportation System with an electrically controlled system that will utilize lithium-based batteries is being assessed. The U.S. Air Force also envisions the use of lithium-based batteries in various applications, such as unmanned aerial vehicles, military aircraft and Earth-orbiting spacecraft. Other governmental agencies, including the Department of Energy (DOE) and the Department of Defense (DoD), also envision the future use of lithium-based battery technologies to enhance or to enable their specific mission needs.

Cell and battery requirements for future NASA and Air Force missions span a wide range and are determined by specific mission

needs, as shown in Table 1. For example, LEO spacecraft and planetary orbiters require batteries that can provide greater than 30,000 cycles at up to 30-40% depth-of-discharge (DOD). GEO applications will require a long calendar life in excess of twenty years. Planetary missions such as rovers and landers require batteries that are capable of operating at low temperatures following the long stand time associated with travel to reach the planet. Some aircraft and RLV applications require high voltage and high capacity batteries with the capability of performing over a very wide temperature range. Commercially available lithium-based cells fail to meet many of the aerospace mission requirements, and the safety of high capacity cells and batteries is also a serious concern for aerospace applications. State-of-the-art lithium-ion cells need significant performance improvements in several areas in order to address aerospace mission needs.

In order to address the advancement of the state-of-the-art of lithium-ion cells and batteries to meet NASA and Air Force mission needs, a collaborative DoD/NASA program effort has been ongoing since 1997. The program utilizes a technical approach focusing on cell design optimization and the development of advanced electrode materials and liquid electrolytes to achieve improved low-temperature performance and cycle life. The program objectives include (1) the development of high performance lithium-ion cells and batteries along with (2) the development of control electronics for "smart" battery management, (3) the establishment of production sources and (4) the demonstration of technology readiness for various mission applications. This program is well established, and results obtained thus far indicate that significant lithium-ion cell performance improvements are being realized.

To address the electrochemical energy storage needs for the next generation of aerospace applications, advanced lithium-based cell chemistries that are coupled with solid-state and/or polymer-based component

concepts are envisioned to be mission-enhancing and mission-enabling technologies. For such future applications, the energy storage subsystem must have minimal mass, while meeting the power requirements of the spacecraft or of the mission-specific device. The current view is that no single cell chemistry will optimally meet all aerospace mission needs. The successful development of such advance technologies will also have significant impact on commercial and terrestrial applications.

PERS Program Overview

Recently, NASA and the AFRL have expanded collaborative efforts to support the development of polymer-based, lithium-based cell chemistries and battery technologies in order to address future aerospace mission needs. The overall objective of this development program, which is referred to as PERS, Polymer Energy Rechargeable System, is to establish a world-class technology capability and a U.S.-based manufacturing resource that will ensure U.S. leadership in polymer-based battery technology for aerospace applications. Once developed, this technology is envisioned to be superior to other conventional battery technologies.

Advanced lithium-based cell chemistries coupled with polymer-based component concepts offer numerous advantages over battery systems employing a liquid electrolyte. An all-solid cell design, which contains no free liquid, offers inherent safety advantages, e.g., no internal pressure buildup, and affords a reduction in system complexity. As the same high unit cell voltages that are exhibited by lithium-based liquid electrolyte cells are achievable, higher specific energies and energy densities, coupled with lower self-discharge rates, are also projected improvements for solid electrolyte cell concepts. A flexible shape factor in cell design will enable integration of the energy storage system with structural or other subsystem entities. Also, the

exploitation of polymer film-based manufacturing technologies is projected to result in significant production cost reductions.

The PERS program will address both near-term and far-term R&D issues and technical challenges that are critical for successful development of the polymer-based battery technology. The initial phases of the program will focus on the development of the critical cell components in order to achieve necessary levels of performance. This includes the development of solid polymer electrolytes, the development of anode and cathode materials that are compatible with the electrolyte and the achievement of desired electrode/electrolyte interfacial properties. The programmatic approach to be taken for this critical component development is to support as many novel R&D concepts and technical approaches as are viable. Some examples of far-term issues and needs are component/cell scale-up, cell/battery designs to address specific applications, complex charge control requirements, subsystem integration issues, thin-film fabrication technologies and the establishment of appropriate manufacturing processes.

The primary near-term PERS program focus is to support the development of a solid polymer electrolyte(s) that exhibits the technical performance necessary for achieving a viable cell/battery. The electrolyte performance requirements include (1) an ionic conductivity of $\sim 10^{-3}$ S/cm or higher in the desired operational temperature range (e.g., -40°C to $+65^{\circ}\text{C}$), (2) a lithium-ion transport number approaching unity, (3) low interfacial impedance, (4) chemical compatibility with electrode materials, (5) a large window of electrochemical stability, (6) low electronic conductivity, (7) good dimensional and thermal stability and (8) mechanical properties that allow scale-up of the manufacturing process. Electrolyte chemistries and concepts under consideration include (1) polymer electrolytes based on "solvent-free" binary salt

complexes, (2) cation-conducting polyelectrolytes, (3) polymer-ceramic composites, (4) inorganic-organic hybrids and (5) hybrid/gelled systems.

Envisioned as a multi-year effort with initial programmatic emphasis on the development of critical cell components and technologies, the PERS program is structured as a collaborative and cooperative national interagency technology development initiative. This approach will not only leverage existing government-sponsored related R&D programs, but it will ensure the effective utilization of government funding, skills and resources to address technology and engineering issues of mutual interest. In February 2000, an Interagency PERS Program Working Group meeting was held to aid in creating the collaborative intragovernmental relationships that are currently being defined and pursued. This forum was invaluable in assessing current R&D programs, identifying key technical issues, and discussing areas of mutual interest for collaboration.

As previously mentioned, the initial phases of the PERS program will focus on addressing the key technology issues and challenges that exist at the cell and component level. In addition to exploiting interagency collaborations, this will be accomplished programmatically by (1) the effective utilization of internal NASA and AFRL facilities, resources and expertise in electrochemistry, battery technology, polymer chemistry and materials science and (2) the collaborative and interactive involvement of both academia and private industry. Several fundamental research investigations in support of the PERS program objectives are in progress, and, recently, a major solicitation seeking new R&D opportunities to pursue has been publicly announced.

The active involvement of the academic and business communities in the PERS program fundamental R&D activities is presently being addressed via the mechanism of a NASA Research Announcement (NRA). This

solicitation for research proposals for open competition focuses on the development of the polymer electrolyte and other cell components of interest to meet envisioned cell-level performance requirements. All polymer-based cell chemistries and concepts are being considered, and successful offerors will be expected to be able to substantiate incremental progress in demonstrating technical feasibility by meeting short-term milestones within their PERS-supported programs.

Several NASA-funded, short-term fundamental research investigations that support the PERS program R&D objectives have been initiated within the past several years. The focus of these investigations is to evaluate a diversity of solid polymer electrolyte chemistries and conceptual

approaches and to perform a preliminary assessment of the "practical" technical feasibility of utilizing these exploratory materials for "liquid-free" lithium-ion transport in lithium-based rechargeable cells. The results of these investigations will be made available in the open literature, as appropriate.

Although still in its infancy, the NASA/Air Force PERS program is committed to the achievement of the future realization of a world-class technology capability and U.S. leadership in polymer-based battery technology. This realization will address NASA and DoD far-term mission needs, as well as supporting the advancement of energy storage technologies for existing aerospace applications.

Parameter	NASA Rovers	NASA Landers	AF Aircraft (A)	AF Aircraft (B)	AF GEO	NASA GEO	AF UAVs	AF LEO	NASA LEO/Plan Orbiter
Nominal Voltage	14	28	270	28	100	28	100	28	28
BOL/EOL Capacity (AH)	7	20	20	20	50	20	200	50	20
Temp Range (°C)	-30 to +45	-20 to +45	-40 to +65	-40 to +65	-5 to +30	-5 to +30	-40 to + 65	-5 to +30	-5 to +30
Life (Cycles)	>500	>500	1,000	1,000	1,500	1,000	1,000	30,000	>30,000
Discharge Rate	C/5 to 1C	C/5 to 1C	C	C	2C/3	2C/3	C	C	C
Charge Rate	C/5 to C/2	C/5 to C/2	C	C	C/20	C/20	C	C/2	C/2
DOD (%)	50	50	50	50	75 (max)	75 (max)	50	25	30 - 40

Table 1. Cell and battery requirements for NASA and Air Force aerospace missions.

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